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A SYSTEM FOR THE GENERATION OF MONOCHROMATIC RADIATION FOR PHOTO-BIOLOGICAL INVESTIGATIONS

G. Schoser

The author describe a recently designed interference-filter monochromator system for biological investigations. The spectral range is from 400-800 nm; the system consists of 16 monochromator units. The output obtained previously by middle-volt projectors (110 V/750 w) is reached here at much lower cost and with much less optical equipment. It operates with newly developed ellipsoid reflector lamps (12 V/150 w, Osram) as the radiation source. Each unit utilizes a simple optical system. The overall efficiency is as good as that of a high power projector (Prado, 750 w, Leitz). The improvements in interference filters do not still require strictly parallel rays in order to prevent stray losses. With filters of the new design, a deviation of 20° causes a change of 1 nm in the wavelength. This makes the system less sensitive to adjustments. They are made by centering the illuminated area.

1. Introduction

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The problems of photo-biology remain unchanged at the center of attention. During past years, monochromatic radiation -- as defined by wavelength in nm and intensity in $\mu\text{w}/\text{cm}^2$ or $\text{erg}/\text{cm}^2 \cdot \text{sec}$ -- has frequently been used to obtain action spectra of the more qualitative kind of biological events. Recently, attention was concentrated largely on its application to the quantitative analysis of photo-biological phenomena. Since the last publications [Mohr and Schoser, 1959 and 1960], remarkable progress was made in the generation of radiation sources, leading to new solutions of a physical-technical nature. The vast interest in the generation of monochromatic radiation for the purposes of photo-biology has stimulated new calculations for the design of simple radiation units which can be operated easily. Particular attention was paid to the following requirements:

1. Simple construction, easy to survey.
2. Low cost combined with the highest possible output.
3. Easy handling by a single operator.

They are interference filter monochromator systems like the ones mentioned in the publications. Within current years, the manufacture of interference filters has made progress as far as spectral purity is concerned. The background

*Numbers in the margin indicate pagination in the original foreign text.

of the filter was further lowered. The testing of the properties of the filter for possible changes, easily carried out by means of a registered spectrophotometer, is the guarantee of spectral purity. Further requirements for ^a/2 an interference filter system are the following [compare also Mohr and Schoser, 1959]:

1. Single wave^alengths can be produced independent of each other or simultaneously.
2. Adjustment of the intensity can be carried out in 3 ways: by regulating the current for the bulbs, by interposing exactly defined neutral color glasses, and by modifying the distance between the object and the source of radiation.

The previously mentioned disadvantage, that only a few ranges of wavelengths can be investigated simultaneously, should be minimized by the construction described here.

2. The Light Source

Research on the monochromator system presented here, lead to the use of elipsoid reflector lamps recently used in narrow film projectors (Figure 1a-c). This type of lamp is particularly suitable since the appearance on the market of an elipsoid reflector lamp, 12 V/150 w. The effective output could be increased considerably by winding a thinner wire around a flat core wire coil. In addition, the structure of the radiation unit is simplified substantially because the auxiliary mirror and the condensor mirror are eliminated. In this kind of lamp, a part of the bulb is the elipsoid reflector. The illuminating body is situated in focus F_1 , and lies on the long axis of the lamp. The highest concentration of radiation is near focus F_2 , which, in turn, is determined by the characteristics of the inner reflector ($F_1 - F_2$ equals 47 mm). The spherical front half is a mirror inside with a 25 mm diameter window for the emerging beam. This mirror surface has the same effect as the auxiliary mirror in the usual condenser lens illuminating systems. The projection of the mirror image of the illuminating body on the illuminating body itself, in original size, closes the gaps in the coil, increases the effective light intensity, and increases the temperature of the coil. This improves the ratio of light output (effective power) to applied power (capacity of the lamp). These effects increase the effective current by 35% without changing the life expectancy. Thus, the elipsoid reflector lamp is, simultaneously, an illuminating body, condensor mirror, and auxiliary mirror combined in a single structural element. This ^h/3 type of lamp also has advantages from the point of view of light technology. The light emanating from the light source is almost completely utilized. Its optical efficiency is near 10% (ratio of effective power : applied power) compared with 0.7 to 1% of the usual projector lamps. The optical properties of elipsoid reflector lamps are also remarkable. A wide angle is illuminated and thus a large aperture. (Projector objectives with a high ratio -- up to about 1:1.2 -- are particularly suitable.) The undesirable colored fringes usually appearing when the light beam is concentrated by means of a mirror are elim-

inated. The illuminating body appears blurred in the window. This prevents the appearance of "stripes". By placing the window near the second focus, stray losses are prevented. It is further advantageous in that the narrowing of the bundle of rays near F_2 has no definite maximum. Small variations in the distance between window and lamp will thus hardly influence the light intensity.

The elipsoid reflector lamp must be mounted upside down (burning position, 15 hrs) to minimize light losses during its life time (25 hrs) caused by blackening of the bulb.

Since 1964, so-called quartz-iodine lamps are commercially available. An iodine cycle process prevents the blackening of the very small quartz bulbs. These lamps have a still higher light intensity combined with a doubling of the life expectancy (50 hrs). Unfortunately, it is technically impossible to combine the advantages of both types of lamps. Research has clearly shown that the elipsoid reflector lamp is more suitable as a light source for photo-biological purposes. A projector with a quartz-iodine lamp is, in its design (auxiliary mirror and mirror condensor), comparable to a middle-volt apparatus (110V/750 w), but with a higher average life expectancy of 50 hrs. Such equipment is mass produced by industry, e.g., Pradovid N 24-J⁸⁴~~88~~.

3. The Irradiation System

To squeeze as many irradiation units as possible into a small area, the constant temperature room was placed in the center, divided in the middle by ¹/₄ a plywood sheet and both compartments connected by a sliding door (Figure 2). On each side are 8 irradiation boxes, also separated from each other by plywood sheets. The constant temperature room itself is a wood frame structure insulated by Styroper sheets, 100 mm thick, masked on both sides by plywood sheets. The temperature control is carried out by a 3-point mercury thermostat for both compartments. Each half of the room has its own unit. The temperature is adjustable from $\pm 0^\circ\text{C}$ to $+40^\circ\text{C}$ ($\pm 1^\circ\text{C}$)*. Since the experiments are carried out mostly in closed systems, no humidity control is provided. A check showed that at $+20^\circ\text{C}$ a fairly constant relative humidity of 60% is obtained.

The monochromatic radiation is produced when the light beam enters the irradiation room through the interference filter. Since the chamber is installed in the attic, it was not necessary to isolate the irradiation units separately. The mutual isolation of the irradiation units was easily achieved by the structure of the shell (see Figure 3). This location also made special precautions for removal of the hot air from the projector unnecessary. The radiation enters through holes 50 mm wide. The placing and adjustment of the radiation unit is identical in all 16 cases. The constant voltage is produced by a Philips product (PE 4225/06, VE = 187 - 242 V, $V_k = 220 \text{ V} \pm 0.1\%$, L = 5.6 kw. Figure 3 shows a cross section through the optical system. All parts are easily accessible. The optics are dominated by the use of the elipsoid reflector projector

*Translator's note: Could they mean 0°C to $\pm 40^\circ\text{C}$ ($\pm 1^\circ\text{C}$)?

lamps, 12 V/150 w, of the Osram Company (Cat. No. 58.8212). This projector lamp with an average life time of 25 hrs. is an illuminating body, auxiliary mirror and condensor mirror, all in one. This offers the advantage of decreased losses from reflection on various surfaces and less dust collection. The lamp is mounted upside down on the wall of the chamber in a centering socket, P 35¹ (burning position, 15 hrs) on an angle iron. The angle iron has oblong holes permitting adjustment of the lamp in a horizontal and a vertical direction. The glass heat shield (KG 1, 2 mm thick, hardened, from the company Schott & Gen., Mainz) and the projector lens ($f = 65$ mm, Plankenkav, Spindler & Hoyer, 15 Göttingen) are screwed to the wall of the chamber, in holders of stamped metal with holding loops, by means of distance holding separators. For better cooling of the protective heat filter, a U-shaped reflector, made from aluminum sheet, is provided. The fan (Maico EFK 20K, 220 V; 0.25 amp, 35 w, 1350 RPM) for generating the cooling air stream is mounted on a bench. A piece of sheet metal attached to it diverts the air stream towards the lamp and the optics. A hood of sheet metal with a chimney covers the radiation unit and is almost impermeable to light. The holder for the interference filter is screwed to the wall of the constant temperature room. It has three supports and two flat springs to secure the filter. The interference filter thus separates the constant temperature room from the outside. A rotating frame is also attached to the wall by means of a two-legged, two-jointed holder. The frame holds the surface mirror (ALFLEX-A or ALFIEX-A with high UV reflection for the blue spectral region; Deutsche Balzers GmbH Geisenheim, Rheingau). This mirror can be fixed in every position. On the table there is the "Laborboy" with the object to be irradiated. It serves as a fine adjustment for the intensity of the radiation. Under the table hangs the transformer for regulating the voltage. A switch on the side of the box makes it possible to turn the lamp and the fan on and off simultaneously. Satisfactory transformers are, e.g., a Trafo with built-in voltmeter: Ismet RU, 0.5 kVa, Schutzart P₂₀ U 220/0-24 V, J = 21 amp (Schlenker and Meier, Schweningen/N) or a FD Ringkern-Feinregler RFR "Labor" resp. FD Ringkern-Feinregler GRFR "Goldring" (Dienes, Mühlheim/Main).

4. Measuring the Radiation

This is carried out by a thermopile galvanometer system as described previously [see Mohr and Schoser, 1959]. The large-surface thermopile E₁ of Kipp & Zonen, Holland, is used as a receiver. The galvanometers used are, as needed, a multiflex galvanometer MGO (Dr. B. Lange, Berlin) or a Kipp Recorder BD 2 (the sensitivity here is $3 \mu\text{W}/\text{cm}^2$ for every scale division).

The calibration is carried out as described previously. The measuring instruments are mounted on a movable table. This makes it possible for one operator to adjust the intensities.

5. The Capacity of the System

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The described optical system produces an almost evenly illuminated circle of about 10 cm, at a distance of 40 cm from the mirror. The deviations are on the order of $\pm 10\%$. This makes the setup more efficient than the Prado arrangement [Mohr and Schoser, 1959]. The system is essentially suitable for the

visible part of the spectrum. At wave^{length} 404 nm (filter AL 404 HW = 23 nm, t = 45%) an intensity of $500 \mu\text{w}/\text{cm}^2 = 5000 \text{ erg}/\text{cm}^2 \cdot \text{sec}$ is obtained.

TABLE I. SUMMARIZES THE PERFORMANCE

Filter max.	t max in %	HW in nm
AL 404	45	23
" 420	43	24
" 431	48	20
" 454	49	13
" 472	49	20
" 505	56	21
" 553	56	18
" 581	50	20
" 603	60	19
" 629	62	20
" 663	51	24
" 674	61	21
" 711	55	17
" 729	61	26
" 753	47	19
" 772	53	17
Additional filters to optionally replace the mounted ones:		
Al 329	60	19
" 650	44	24
" 690	59	21

6. Discussion

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The described arrangement is an attempt to show how, in a technically simple way, it is possible to produce relatively high intensities combined with good spectral purity. The output obtained in the past by the middle-volt projectors (110 V/750 w) is reached here at much lower cost and with much less optical equipment. The improvements in interference filters do not ^{still} require strictly parallel rays in order to prevent stray losses. With filters of the new design, a deviation of 20° causes a change of 1 nm in the wavelength. This makes the system less sensitive to adjustments. They are made by centering the illuminated area.

In summary it can be said that this presentation is a further contribution to the generation of monochromatic radiation, based on interference filters, applied to the solution of photo-biological problems. The author is grateful for further criticism and eager to advance the technical-optical development.

7. Summary

A recently designed interference-filter monochromator system for biological purposes is described. The spectral range is from 400 nm - 800 nm. The system consists of 16 monochromator units. It operates with newly developed ellipsoid reflector lamps (12 V/150 w, Osram) as the source of radiation. In each unit a simple optical system (see Figure 3) is used. The efficiency of this system is as good as that of a high power projector (Prado, 750 w, Leitz). For irradiation in the visual part of the spectrum, these units show some advantages in handling, service and maintenance compared with former ones.

The Deutsche Forschungsgemeinschaft supported this development by substantial assistance. Thanks are due to Dipl. Ing. Sauer of the Osram company and Messrs. E. Sinner and H. Schaal for the construction of the constant temperature room and the radiation unit. The conditioning unit was built by the firm K. F. Stiel, Tübingen. The electric installations were carried out by the firm Pfuderer & Hess, Tübingen.

Legends for the Figures*

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Figure 1: Elipsoid reflector lamp^{by} Osram, No. 58.8212; 1a = in front view; 1b = in side view; 1c = seen from below. The dotted areas are mirrors inside and dull outside.

Figure 2: Division of the monochromator setup with 16 radiation units seen from above. The numbers in the boxes give the wavelength of the radiation unit in nanometers (nm). 1 = radiation unit; 2 = irradiated area with table top; 3 = boxes; 4 = conditioning unit; 5 = thermostat; 6 = separating wall with sliding door; 7 = insulating wall of the constant temperature chamber (see details in text).

Figure 3: Radiation unit (vertical cross section through the optical axis); 1 = insulating wall; 2 = interference filter holder with springs; 3 = interference filter (removable); 4 = ALFLEX surface mirror; 5 = irradiated area with table top (and possibly "Laborboy"); 6 = the angle iron with oblong holes for adjusting the projector lamp; 7 = hood of the radiation unit with a chimney for removal of the hot air; 8 = lamp socket, P 35s; 9 = sheet reflector for the fan to direct the cooling air; 10 = ellipsoid reflector lamp 12 V/150 w, Osram; 11 = glass heat shield KG 1, 2 mm thick, hardened, with attached U-shaped aluminum sheet reflector for improved cooling of the filter and holder; 12 = projector lens with holder; 13 = shell of the wind channel; 14 = fan, Maico EFK, 20K (220 V, 35 w, 0.25 amp, 1350 RPM).

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